

A Summary of Two Recent UAS Command and Control (C2) Communications Feasibility Studies

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Abstract— In Spring of 2015, the NextGen Institute conducted two UAS C2 Communications Feasibility Studies on behalf of the FAA UAS Integration Office to develop two limited UAS C2 operational examples, each involving low-altitude BLOS (Beyond Line of Sight) Line of Communication (LOC) UAS applications, as part of assessing the myriad practical UAS C2 deployment challenges associated with these approaches. The studies investigated the feasibility of “Point-to-Point” (PTP) and “Network” approaches to UAS C2 to better understand potential user needs and to explore evolutionary paths to establishing a nation-wide system for delivering UAS C2 communications. This paper will summarize the solicitation, approach and results of the two studies teams led by Aviation Management Associates, Inc. and Exelis Inc.

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1. INTRODUCTION

In order to support the safe operation of Unmanned Aircraft Systems (UAS), the ITU World Radiocommunication Conference (WRC-12) held in January 2012, afforded aviation a new allocation to the aeronautical mobile (route) service (AM(R)S) in the C-band (5030 – 5091 MHz) for line of sight UAS Command and Control (C2) links (similar ITU terminology: Control and Non-Payload Communications),

limited to internationally standardized aeronautical systems. An existing C-band allocation to the aeronautical mobile satellite (route) service (AM(R)S) was similarly modified for beyond line of sight (BLOS) C2 links. The FAA intends to meet safety and operations requirements using this spectrum resource. The September 2012 FAA Concept of Operations, “Integration of Unmanned Aircraft Systems into the National Airspace System,” calls for establishment of the capability to enable Command and Control (C2) connectivity between pilots-in-command (PICs) and UAS. The FAA’s UAS Integration Office (AFS-80) is responsible for directing and coordinating efforts associated with fulfilling such requirements. During the past year, they have had several studies that help define the path forward.

In February 2015, the Titania Solutions Group, under contract to the FAA’s UAS Integration Office prepared a report “Spectrum Management for Unmanned Aircraft Systems Command and Control - Report on Models, Authorities, and Process”¹ to evaluate options for managing access to existing radio spectrum allocations that are available for Command and Control (C2) operations for unmanned aircraft systems (UAS). The report examined the legal and regulatory processes related to spectrum management generally, analyzed four possible models for spectrum management in the context of UAS C2 links, and discussed the relevant agency processes and other logistical concerns related to implementation of these Models: FAA-Managed; Frequency Coordinator; Band Manager; and, Commercial Service Provider.

The NextGen Institute was tasked by the FAA UAS Integration Office to develop two limited UAS C2 operational examples, each involving low-altitude (visual) beyond line-of-sight (BLOS) Line of Communication (LOC) UAS applications, as part of assessing the myriad practical UAS C2 deployment challenges associated with these approaches. In January 2015, they solicited for proposals to study of the feasibility of two approaches to UAS C2 to better understand potential user needs and to explore evolutionary

paths to establishing a nation-wide system for delivering UAS C2 communications:

1. “Point-to-point” (PTP) UAS C2 provided by the operator of the aircraft (or a third party) presumably using a repeater system, or the like. During a UAS flight using this approach, a single channel, or increment, of UAS C2 spectrum would be required.
2. “Network” UAS C2 provided by rights-of-way owner-carriers and/or third party carriers presumably involving a shared network. During a UAS flight using this approach, multiple channels, or increments, of UAS C2 spectrum would be required for the entire distance of the flight, where the UAS C2 was “handed off” from one constituent asset to the next.

Either the PTP or the Network approach could provide UAS C2 communications. Moreover, both approaches could be in use simultaneously under an appropriate governance and control framework during some period of the infrastructure evolution. Shedding additional light on how and where the C2 infrastructure might begin to evolve and how a nationwide system might develop are objectives of the feasibility studies to be commissioned under this solicitation. Working with the FAA’s UAS Integration Office and NASA, they defined several areas of interest to be investigated to understand more completely the practical operational advantages and disadvantages associated with UAS C2 requirements for individual flights, such as the following:

- End-to-end BLOS UAS flights
 - Variety of flight “missions” (e.g., pipeline inspection, package delivery, photographic services, etc.)
 - Operational assessment of current C2-spectrum-related limitations on BLOS UAS flights
 - Infrastructure requirements and availability
- Scheduling and allocation approaches for managing C2 bandwidth
 - Assessment of the two alternatives for how infrastructure may be provided initially
 - Assessment of scalability for each alternative approach to regional and national systems over time, including potential for avoiding stranded technology investment
 - Assessment of potential hybrid system where both approaches coexist for some period of time (including an indeterminate period if appropriate)
 - Business models for BLOS UAS infrastructure under each alternative
- Benefits to be derived by UAS service subscribers (e.g., buyers of UAS services)
 - UAS services to be provided for a fee (e.g., operators)
 - UAS C2 services provisioning business drivers and potential user fees
 - Margin objectives, breakeven points, cost elements, other related drivers of business viability
- Technology evolution and refresh considerations, Regulatory concepts, governance and accountability for UAS C2 infrastructure assurance under each alternative

- Safety concerns and drivers
- Reporting needed and acceptable reporting latency
- Fault scenario analyses, consequences and mitigations

The 3-month study approach was developed to assess the feasibility and viability of a proposed low-altitude LOC UAS application under both the PTP and Network models based on a specific scenario proposed by the team. Two key assumptions and an example scenario and guidelines were specified:

- Assume that the C2 spectrum would use the 5030 – 5091MHz C-Band allocation.
- Assume all Air Traffic Control (ATC) functions are provided and outside the study boundaries; the study is limited to issues and challenges of providing the UAS C2 functionality that replaces the pilot in cockpit for controlling the UAS.
- This example scenario involves a UAS conducting a LOC (Line of Communication) inspection BLOS such as pipeline inspection; power utility right of way (ROW) inspection; railroad ROW inspection, etc.
- The study should consider UAS flights covering at least 200 miles of linear ROW and up to 1,000 feet above ground level (AGL) so as to demonstrate the need for and explore issues associated with BLOS UAS C2 infrastructure.
- The assessment would encompass elements such as using fixed C2 infrastructure vs. temporary infrastructure that is “stood up” for the mission and taken down between missions.
- Technology tradeoffs would include equipage considerations, bandwidth requirements, transmission power characteristics, interference issues, etc.
- Business tradeoffs would consider value to ROW owner, prices and lifecycle costs to UAS operator, prices and costs to C2 provider (if a different entity from the UAS operator).

In March 2015, two proposal teams were selected: Aviation Management Associates, Inc. and Exelis Inc. The studies were completed over three months and the complete final reports are available on the NextGen Institute’s website (references 2 and 3). The remainder of the paper will include an executive summary of both reports and overarching conclusions.

2. “UAS COMMAND AND CONTROL COMMUNICATIONS FEASIBILITY STUDY” LED BY EXELIS, INC.

Introduction and Scenario Overview

This study was conducted in early 2015 by Exelis Inc. and the University of Alaska Fairbanks (UAF) to assess the feasibility of alternative C-Band terrestrial based command and control (C2) communications approaches for supporting low altitude unmanned aircraft system (UAS) inspections over the 800 mile length of the Trans-Alaska Pipeline System

(TAPS), also known as Alyeska Pipeline. The objectives of this study were to identify and more completely understand “the practical operational advantages and disadvantages associated with UAS C2 requirements for individual flights” in four major areas: End-to-end BLOS UAS flights, Infrastructure requirements and availability, BLOS infrastructure business models for C2; and Regulatory concepts, governance, and accountability for UAS C2 infrastructure assurance for each C2 approach. The selected study scenario area is depicted Figure 1.

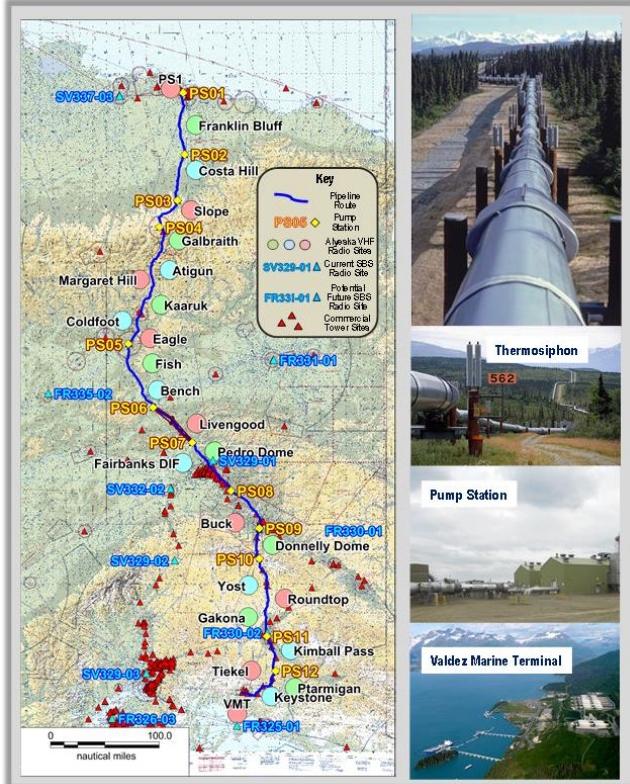


Figure 1 – Overview of TAPS Oil Pipeline Scenario

The oil pipeline C2 scenario illustrates a C2 paradox that the easiest areas to implement C2 systems are in urban infrastructure environments; however these areas typically have denser air traffic that may be more difficult to approve for UAS operations because of airspace management and safety issues. Austere environments such as Alaska may have UAS operations being approved faster by the FAA because of operational needs and lower risks associated with aviation near rural areas. Of course, it is also understood that UAS BLOS operations in typical Alaska environments may be more difficult to implement because of the lack of C2 infrastructure, including commercial telecommunications systems.

Table 1 represents a descriptive overview of the study scenario, with elements common to both the PTP and networked C2 communications system approaches. Table 2 summarizes the differentiating assumptions for the PTP and the networked C2 system approaches.

Table 1 - TAPS LOC BLOS Inspection Scenario

| Scenario Parameter | Description |
|--|---|
| Summary Description | Line of Communication Beyond Line of Sight (BLOS), low altitude inspection of TAPS |
| Infrastructure length and end points | 800 miles (1,287 km) from Prudhoe Bay, to Valdez, Alaska |
| Associated infrastructure and facilities | Prudhoe Bay Oil Field (origin), Valdez Marine Terminal (terminus), 12 pumping stations, AT&T leased VHF radio/telephone system with 25 repeater stations, one operations control center, and two remote emergency operations centers |
| Pipeline owner | Alyeska Pipeline Service Company |
| Current Inspection Needs | <ul style="list-style-type: none"> Pipeline & Hazardous Materials Safety Administration (PHMSA) requires ROW visual inspection 26 times per year with additional closer inspection as needed Regular and persistent patrolling of the pipeline ROW and key facilities for monitoring and assessing risks (e.g., leaks, encroachments, geological instability, etc.) Close range inspection and imaging of 122,000 thermosiphon facilities to mitigate permafrost thaw and other Arctic geotechnical engineering issues |
| Current Inspection Methods | <ul style="list-style-type: none"> Aerial inspection via helicopter and other manned aircraft (due to Alaska's austere aviation environment, manned helicopter operations cost ~\$14,000 per day) Ground vehicle (automobile, all-terrain vehicles, or snowcat) inspections when necessary, e.g. flagged via aircraft for further investigation, inclement weather. |
| UAS Operational range and altitudes | <ul style="list-style-type: none"> Assume minimum range of ~100 nm between pump stations along a total of 800 mile pipeline ROW Altitudes from 100 feet to 2000 feet above ground level (AGL) (current operations is 40 to 400 ft. AGL), up to 2000+ feet AGL for Hybrid and Network operations Includes within and beyond visual line of sight (BLOS) |
| Airspace classes of operations | Class G,E, and D airspace ranging from very remote low density airspace to a mix of commercial, general aviation, and military aircraft operations in the Fairbanks area |
| UAS Level of Automation Assumed | Consistent with RTCA SC-228 assumptions, Pilot in the Loop (PITL) UAS control is exercised, i.e. UA autonomy is not allowed, except in degraded and/or off-nominal conditions, such as the Lost Link condition. |
| Regulatory Considerations | Assumes C2 service provider is same as UAS service provider with respect to obtaining FAA certification of C2 system |
| Study Assumptions per the Solicitation | <ul style="list-style-type: none"> Focus of study is on terrestrial C2 solutions; SATCOM solutions were not considered C2 spectrum will use ITU-R specified 5030 – 5091 MHz UAS C-Band allocation All ATC functions are provided and handled outside the scope of this study |

Table 2 - C2 Alternative Specific Scenario Assumptions

| Scenario Parameter | Point-to-Point Approach Assumptions | Networked Approach Assumptions |
|--|---|--|
| UAS C2 service end user(s) | Single pipeline company, i.e. Alyeska, which conducts its own inspection, (not typical in the oil pipeline industry) | Alyeska pipeline company and potential users / applications <i>not necessarily within the pipeline ROW</i> : <ul style="list-style-type: none">• Third party pipeline inspection companies, if required• Bureau of Land Management, State Dept. of Forestry (forest fire fighting)• Dept. of the Interior (wildlife observation)• Fairbanks police and fire• Alaska State Troopers |
| C2 system interoperability | “Closed” system limits access only to UA specifically designed for that system. Specifications may be proprietary. | C2 service provider publishes UA interoperability standards required for use of the network |
| Number of simultaneous unmanned aircraft in operation | Multiple UAs along different sections of pipeline (they use five helicopters today), but assume one per C2 station because of single frequency operation | Multiple UA for multiple users |
| C2 service coverage capabilities | Only along pipeline ROW at up to 2000 ft. AGL | <ul style="list-style-type: none">• Pipeline ROW at up to 2000 ft. AGL• Other areas as required for additional end users of the network |
| C2 comm service provision options | Third party C2 service provider using existing leased infrastructure (VHF radio stations), leased commercial telecon sites as needed to provide gap filler coverage, new infrastructure owned and operated by C2 service provider | Third party provides C2 services using combinations of: <ul style="list-style-type: none">• Existing leased infrastructure (VHF radio stations)• New infrastructure built and owned by C2 service provider to provide coverage to other users within and outside of Alyeska ROW coverage• Other existing leased commercial telecon infrastructure |
| UAS C-Band protected spectrum channel operational requirements options | <ul style="list-style-type: none">• Single channel/frequency is periodically assigned to user (Alyeska or third party C2 provider) as needed, over UAS pipeline ROW flight path based on reservations | <ul style="list-style-type: none">• Multiple frequencies within a fixed pool of frequencies assigned to the service providers radio stations assigned as needed to the C2 service provider for oil pipeline inspections and other end-user services based on reservations. Frequency broker has technical capability and responsibility to mitigate |

| Scenario Parameter | Point-to-Point Approach Assumptions | Networked Approach Assumptions |
|---|--|--|
| | <ul style="list-style-type: none">• Single channel/frequency is permanently assigned to user (Alyeska or third party C2 provider), over UAS pipeline ROW flight path | co-channel interference operation for C2 service providers. <ul style="list-style-type: none">• A sufficient number of multiple frequencies are permanently assigned to the service providers to prevent co-channel interference among the network radio sites, based on C2 service provider design. |
| Mobility management, including handoffs | Based on single channel operations | <ul style="list-style-type: none">• Multiple channel operations, may rely more on use of upper layer protocols• Also potential for handoffs between other networks |
| Regulatory/Safety Considerations | Third party C2 provider is responsible for certifying system, which includes developing and submitting safety case. Upon approval, responsible for system safety. | Third party C2 provider is responsible for certifying system, which includes developing and submitting safety case. Upon approval, responsible for system safety. |

Conclusions:

Task 1: Operational Assessment - End-to-End BLOS UAS Flights: Suitability to support flight mission variety; Spectrum limitations; Link/Mobility; Management Issues

Principal factors that distinguish a C2 network system from a Point-to-Point (PTP) C2 system include: 1) point-to-multipoint, multiple frequency operation (for C2 network systems), and 2) greater interoperability in C2 network systems provided through “open” accessibility to C2 network airspace for potential unmanned aircraft (UA), typically enabled through “open” standards. By contrast, a PTP C2 service provider could implement a more proprietary system, since interoperability with other systems is not required.

Operational limitations in the PTP C2 systems were mainly due to coverage limitations necessitated by a single end user (i.e. Alyeska Pipeline), and lack of flexibility because of single frequency operation. The coverage limitations in the linear PTP Radio Station (RS) topology can be offset by adding new RS to fill required coverage gaps outside the coverage corridor, and by adding and/or upgrading radio equipment at existing PTP RS, thus creating a Hybrid C2 system. As an evolutionary path, upgrading existing PTP RS to handle point-to-multipoint operations, along with adding any new RS required for additional coverage would ultimately result in a fully networked C2 system.

Common to the RTCA SC-228 WG2 Dynamic Spectrum Assignment Subgroup and the Titania Spectrum Management Report¹, are the recommendations for: 1) real time, comprehensive flight planning and interference assessment tools to be used by the spectrum management/assignment entity, and 2) web portal like functionality that allows for real time access by the spectrum user/requester.

Unfortunately, the current RTCA SC-228 WG2 C2 Minimum Operational Performance Standards (MOPS) are hampered by the lack of interoperability standards that could define standard link/mobility management approaches.

Task 2: Technical Assessment - Infrastructure Requirements & Availability: Flexibility; Interoperability; Scalability; Spectrum efficiency/capacity; Hybrid operations

Using a novel linear programming optimization process on an initial set of the 57 best available site locations, it was found that it is not possible to reach 100% coverage along the entire TAPS right of way (ROW) until reaching UA operational altitudes of around 1000 ft. above ground level (AGL) or greater. For the 100 foot AGL coverage goal for this study, the best that can be achieved using that set of RS sites is 83 percent coverage (for 40 total sites). Optimizing over an additional 92 sites, it was found that more than 91 percent pipeline coverage at 100 ft. AGL could be achieved with 61 sites.

The optimization methodology optimized for minimum overlap and maximum total coverage, mainly in the interest of requiring the fewest sites and hence reducing costs. This leads to significant portions of the pipeline with little redundancy, which might not be the ideal case for purposes of efficient handoffs. In an actual design and implementation, further optimization would be required.

For those areas of the pipeline route with inadequate coverage several alternatives or combinations of alternatives could be considered: 1) Increase the height of the existing towers proposed at the pump stations, 2) provide pipeline surveillance coverage with manned aircraft later be augmented by SATCOM C2, 3) provide unmanned surveillance at a higher altitude, then deploy manned aircraft to provide inspection at lower altitudes as needed to perform closer checks, and 4) deploy unmanned aircraft C2 “repeaters” at pump sites. Consistent with the current RTCA SC-228 Terms of Reference, the alternative of allowing for autonomous UA operations over those pipeline sections without RS coverage was not considered

For a Hybrid case which assumes that the PTP infrastructure is already in place and operational, the new sites would have to be selected to provide the new coverage in the coverage areas most beneficial to the planned expanded set of end users while striving to minimize cost risks in selecting new sites.

In considering the comparative flexibility, scalability, and capacity, please note that the PTP, Hybrid, and Network C2 Systems can be viewed as three stages in an operational continuum of the same basic C2 architecture and infrastructure as it evolves to accommodate more and more end users, with the distinguishing characteristic being to what extent point-to-multipoint capability has been implemented.

Task 3: Business/Financial Assessment - Infrastructure

Business Models: End user costs/benefits; C2 service provider costs/benefits; UAS service provider costs/benefits

Based on an assessment of the C2 business model viability, it is concluded that a C2 PTP infrastructure solely for Alyeska use does not appear to be cost effective, and even with all users considered, the per flight hour fee to enable an acceptable return on investment may be too costly for the market to bear for a C2 infrastructure providing coverage down to 100 ft. AGL along the entire pipeline.

Consideration should be made for the expansion of the C2 infrastructure to include additional services or to accommodate other end users, but which does not significantly increase the C2 infrastructure costs (e.g. a Hybrid C2 system). This could add substantial value to the use of the service. For example, Alyeska has a desire for real-time video for pipeline monitoring and spill response.

Task 4: Regulatory Assessment - Governance & Accountability: Safety – all operational modes; Certifiability; Performance Monitoring

The study included a brief discussion of the UAS safety analysis process conducted in the context of the FAA’s Safety Management Process, some safety relevant UAS C2 infrastructure design considerations, and some aspects of a very high level and preliminary safety analysis.

The FAA’s Small Airplane Directorate has provided RTCA SC-228 WG2 an excellent overview of the UAS certification process and issues. An important question to ask is: where does a potential UAS C2 service provider fit into the UAS certification process, i.e., what is the process for certification if the UA platform and Ground Control Station (GCS) comes from one source and the C2 services come from a different source?

Two general observations regarding relative certification issues for PTP and Network C2 system can be made at this time: 1) the certification process for UAS provided as a service and composed of constituent services, such as a C2 service and a DAA service, from multiple sources needs to be better understood; and 2) a PTP C2 system deployed as part of a turnkey, owner/operator UAS service/system may face a less complex certification challenge

Recommendations

Task 1: Operational Assessment - End-to-End BLOS UAS Flights

1. Policy decisions based on PTP and Network C2 Systems as separate and distinct classes should be discouraged because PTP, Hybrid, and Network C2 systems can be viewed as three stages in an operational continuum of the same basic C2 architecture and infrastructure.
2. Both ad hoc and fixed PTP C2 systems should always be accommodated in the UAS operational arena, even after C2 network systems have been deployed in the same general area. Therefore, by policy, a dynamic spectrum assignment system should provide equal and equitable access to all qualified PTP and C2 systems, even if this means sub-banding or segregation of the spectrum.
3. The Titania Spectrum Management report sponsored by the FAA should be provided to RTCA SC-228 WG2. This would promote a more common level of understanding of the UAS regulatory environment among that group.
4. Lack of UAS C2 technical interoperability standards presents a serious impediment to the widespread and harmonious implementation of UAS C2 systems and associated spectrum allocations/assignment processes, and should be given a higher priority in future standards development activities.

Task 2: Technical Assessment - Infrastructure Requirements & Availability

1. UAS C2 system infrastructures should be implemented using radio systems based on accepted aeronautical standards, such as RTCA MOPS, as these typically lead to a more straightforward FAA certification path. Also C2 systems should be compliant with relevant ITU-R recommendations.
2. A detailed site/coverage selection process optimizing for both performance and costs, such as that outlined in the study, should be used for planning UAS PTP, Hybrid and Network C2 radio systems with multiple, fixed RS infrastructure.
3. Consideration should be made for installing Hybrid or Network capable infrastructure (e.g. multichannel radios) at selected RS for increased flexibility, capacity and potential revenue capabilities to offset the relatively high capital costs for austere, challenging terrain areas such as Alaska.

Task 3: Business/Financial Assessment - Infrastructure Business Models

1. Additional analysis should be performed for the C2 business models to include additional tradeoffs across technical, operational, policy, and business considerations as those considerations become more defined. There are multiple unknowns that are apparent in these business models such as cost and management of C2 radio spectrum, the regulatory environment for BLOS UAS operations, technology acceptance by regulators, and ultimately the perception of risk with adopting new UAS technology.

2. Consideration of the C2 infrastructure should include additional services (e.g., payload data) that do not markedly increase the C2 infrastructure costs, but can add substantial value to the use of the service.
3. This analysis is specific to the TAPS use case. Additional analysis should be performed as applied to pipeline use cases in the continental United States (CONUS).

Task 4: Regulatory Assessment - Governance & Accountability

1. UAS C2 system safety assessments should be consistent with the FAA's Safety Management System (SMS) to facilitate the certification process.
2. Additional clarification is needed from the FAA on the process for certifying a UAS composed of facilities, equipment, and potentially services provided by multiple sources.
3. Exelis recommends that UAS C2 systems implement a technical performance monitoring (TPM) system using a methodical process similar to the presented approach to ensure selection of appropriate measurement data parameters.

3. “NEXTGEN INSTITUTE UAS COMMAND AND CONTROL COMMUNICATION FEASIBILITY STUDY” LED BY AVIATION MANAGEMENT ASSOCIATES, INC.

Introduction and Scenario Overview

The use of a case study as a basis for analyzing UAS C2 operational, technical and economic issues was chosen because it provided the best opportunity to evaluate real world needs, opportunities and constraints in the context of the Study objectives. As a result, the Study Team partnered with the State of Colorado Mesa County Sheriff’s Office, an FAA approved UAS operator, to better understand user scenarios, needs and applications for UAS BLOS operations.

The Mesa County Sheriff’s Office (MCSO) currently flies a variety of public safety missions within visual line-of-sight of the UAS operator and in daylight hours only. These requirements constrain the potential value of the UAS capability by limiting the times and range of the use of the UAS fleet. The ability to operate BLOS over a year has the potential to double the availability of the UAS to support law enforcement and public safety needs within Mesa County. Further, the Falcon UAS owned and operated by Mesa County has the ability to operate up to 5 miles away from the operator but is currently restricted to approximately one-half mile due to limitation of the operator’s visual acuity. MCSO operates two UAS systems one is the Draganflyer 4X-ES and the other is the Falcon UAS. These operations have been approved under an FAA Certification of Authorization (COA). The ability to fly beyond line-of-sight would improve search and rescue and suspect apprehension missions. In a search and rescue operation, the operator must relocate the Ground Control Station (GCS) on a regular basis

to expand the search area. Generally, the GCS is moved almost every flight, which requires recovering the UAS and breaking down, setting-up and re-launching the UAS each time the GCS is moved to a new location. Ultimately the Visual Line of Site (VLOS) limitation slows search operations and the range and timeliness of the search. Search timeliness is critical in some life-endangered situations. The Falcon currently has a 5-mile link range versus the 0.5-mile VLOS range. The difference is than 1 square mile search area for VLOS versus a 78 square mile search area for BLOS. Launch and recovery also provide the greatest amount of risk to damaging equipment that would be reduced with fewer launch and recovery events.

Future Point-to-Point Operations: The infrastructure requirements to support UAS C2 are different for point-to-point communications versus networked communications. Both alternatives will require fixed or portable assets for radio communications that are beyond line-of-sight. From an operational perspective point-to-point communications involve the radio relay through one or more intervening locations of C2 from the vehicle control station to the vehicle. Relays can be fixed and/or portable locations. Relays receive and retransmit radio signals at higher power for increased range or around obstructions that could block or attenuate the originating signal. Relays can operate between one another on different frequencies than the originating signal as well as function in a duplex mode. The repeaters can be an active or passive microwave relay or a traditional analog radio.

Future Networked Operations: It is envisioned from conversations with the Digital Trunked Radio System (DTRS) and First Responder Network Authority (FirstNet) representatives that DTRS infrastructure in the State of Colorado will continue to be upgraded in support of the Land Mobile Radio (LMR) narrowband network. These upgrades of cell tower power backup systems and data links to the cell sites, including microwave relay links (MRL) and fiber optic cables, add both robustness and capacity to modernize the First Responder mission critical network. Importantly this modernization paves the way for a future migration to the FirstNet LTE broadband digital voice and data network

Beyond Line-of-Sight Scenario

The Mesa County Sheriff's Office has a mission requirement for flying over 200 miles to search for stranded motorist along the major roads in Mesa County. The route includes Interstate I-70, which carries the heaviest traffic and averages about 5,000 feet Above Mean Sea Level (AMSL). Route 330 in the east has a pass at 8,000 feet AMSL. Route 65 in the southeast passes the Powderhorn Mountain Resort at 8,000 feet AMSL and Route 141 in the southwest that has a pass at 7,000 feet AMSL.

The Department's UAS vehicle will plan to fly at 400 feet AGL and will descend as necessary to 200 feet AGL to circle temporarily over stranded citizens to determine the condition of their safety. MCSO will file a four dimensional mission plan that defines the UAS flight time, flight duration and

route and altitude, spectrum band and bandwidth required in RTCA SC228 "quanta", FAA air vehicle identification, pilot name and contact information, surveillance and contingency information including lost link procedures with the Federal Aviation Administration or its agent.

Point-to-Point Command and Control: For the purpose of this study, we assume use of the existing (9) DTRS locations currently installed in Mesa County, CO for siting the C2 C-Band radios (Figure 2). These existing sites are strategically located throughout Mesa County to provide APCO-25 (P25) Common Air Interface Exclusive UHF (700/800 MHz) Voice/Digital Communications to authorized First Responders providing emergency services throughout the Mesa County area. The study assumed a conservative capacity of 200 UAS which is in excess of the needs of Mesa County. Through significant technical analysis, it was concluded that a relatively simple and inexpensive PTP network will provide sufficient capacity for Mesa County and that a transition to a more complex and more expensive Network approach is not needed for the foreseeable future (through 2035).

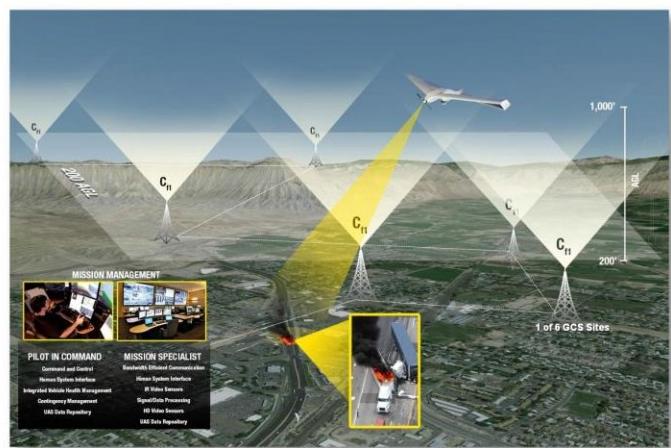


Figure 2 - PBLOS Single C-Band Channels

Networked Command and Control: Networked BLOS refers to dynamically assigning channels to the UAS as it travels along its mission route, similar to a cellular phone network dynamically assigning channels to a user's cell phone as user changes location during the day. Should a networked system be implemented into Mesa County, MCSO would subscribe to the service and receive access keys one time. MCSO would have no need to apply for channel assignments for each mission. The NBLOS design and associated investment in RF equipment will be strongly affected by the Peak Load assumptions and Peak Load mitigation algorithms. Subclasses of UAS vehicles could receive varying levels of service.

PBLOS vs. NBLOS: The network provider must make a PBLOS versus NBLOS deployment decision for each location. A PBLOS Network is notionally less expensive to deploy while an NBLOS Network has greater capacity and flexibility. The PBLOS radios and antennas are less

expensive, but an NBLOS implementation may require fewer ground stations radios and antennas. Airborne PBLOS radios and antennas are less expensive than NBLOS radios and antennas. Each existing UAS VLOS operator has his own cost tradeoffs when deciding to invest to fly BLOS. The less expensive PBLOS equipage increases the probability of the UAS operator subscribing to the BLOS service, although every location and user will have their own unique demand and cost trade dynamics. Several of the key high-level performance parameters are identified in Table 3. Identification of these PBLOS and NBLOS parameters provide the C2 RF Infrastructure designer with opportunities to evaluate the impact of trading both acquisition and operating cost versus UAS system performance.

Table 3 BLOS Network Advantages and Disadvantages

| BLOS Network | Advantages | Disadvantages |
|--------------|--|---|
| PBLOS | <ul style="list-style-type: none"> • Lowest Cost Radio Nodes (UAV and RGS) • Single Fixed Quanta Channel Assignment • Reduced Network Controller Cost & Complexity • Supports Limited Simultaneous Missions (UAVs/PBLOS) | <ul style="list-style-type: none"> • Reduced Spectrum Flexibility • Fixed Bandwidth Channels • Unable to support multiple UAVs/RGS • Unable to support high UAV Density |
| NBLOS | <ul style="list-style-type: none"> • Increased Spectrum Utilization & Flexibility • Dynamically Channel Quanta & Bandwidth • Able to support multiple UAVs/RGS • Able to support high UAV Density | <ul style="list-style-type: none"> • Higher Cost & Complexity Radio Nodes (UAV & RGC) • Increased Network Controller Cost & Complexity • Does Not Support Class 5 UAS Operations |

Summary Points

- Point-to-Point Beyond Line-of-Sight (PBLOS) offers lower implementation and operating costs while Networked Beyond Line-of-Sight (NBLOS) promises higher capacity and a richer potential feature set.
- PBLOS is suitable for Mesa County Colorado through 2035 and is likely suitable for all but the most dense locations initially.
- The tipping point to NBLOS will be a function not only of demand, but the rapidly evolving cost and functional trades between PBLOS and NBLOS.
- Hybrid Networks are accomplished by allocating Spectrum Quanta between PBLOS and NBLOS. Transition from PBLOS to NBLOS is straightforward. Hybrid networks will be common and persist for an extended period.
- The technical demarcation between PBLOS and NBLOS is subjective and perhaps unnecessary. Evolving

technologies will likely create many variants of BLOS networks.

- BLOS Network capacity can be increased by reconsidering RTCA SC228 “continuous communications” and reducing the repetition rate and introducing additional Frame Structures for certain classes of UAS vehicles/missions.
- Interoperability between adjacent BLOS C2 networks will have a significant impact on the operational and financial efficacy of the nation’s UAS BLOS rollout and operations.
- Infrastructure costs will drive UAS C2 implementation to utilization of existing infrastructure like that envisioned for FirstNet.

Key Recommendations

- Beyond Line-of-Sight (BLOS) Network Capacity: Study and Demonstrate possible exceptions to RTCA SC228 Continuous Communications to optimize spectrum utilization (maximize simultaneous UAS Operations) including the Repetition Rate and the TDD frame structure. The exceptions should be made against a matrix of vehicle and mission parameters.
- Interoperability: Study and Demonstrate a UAS transitioning between BLOS Networks operated by different vendors. What are the minimum Network Standards to guarantee interoperability without limiting communication command and control (C2) operator innovation by implementing proprietary wave forms, modulations, etc. to bring improvements in bandwidth, security, quality of service, and to enable unique features?
- FirstNet: Engage FirstNet to explore leverage points for reducing the infrastructure investment and operating costs for UAS BLOS C2 services. Leveraging existing infrastructure is critical to a Public Private Partnership scenario UAS BLOS C2 service business case.

Economic Analysis

A business case analysis has identified a number of critical issues that may preclude the successful deployment of a nationwide UAS C2 network. First and foremost the development, deployment, operation and maintenance of a nationwide dedicated UAS C2 terrestrial network by the FAA would entail expenditures of hundreds of millions of dollars, money the Study Team cannot envision the FAA expending in the near or mid future. This seems particularly challenging when there is no defined or validated demand or projected market for low altitude UAS C2 BLOS. In view of these concerns the Study Team concluded that a Public-Private Partnership would best serve economic viability needed to deploy any UAS C2. In other words the FAA in conjunction with the NTIA and FCC would license the 5030 to 5091 MHz spectrum to a commercial entity to fund, develop, build, deploy, operate and maintain a UAS C2 network in exchange for the collection of user fees for UAS C2 communication services. While a PPP is attractive from the government investment perspective, as previously mentioned, the lack of

an established or soundly projected future market imparts significant risk to a commercial entity in funding a dedicated UAS C2 network. Of course, the FAA could assume some of this risk by virtue of providing initial PPP funding under develop and build. Given the costs and risk involved this does not seem likely under today's government funding constraints. It is obvious due to the high financial risk of investing in a yet unknown UAS C2 network, that additional considerations need to be given to reducing costs and raising revenues to mitigate these risks.

It is known, based on current experience that UAS C2 bandwidth demands pale in comparison to payload bandwidth requirements, especially those demands for mission critical high-resolution real-time streaming video. The ability to link UAS C2 communications with payload communication in terms of diverse (not competing with UAS C2) but bundled service is key to maximizing the revenues needs to justify future UAS C2 investments. The expansion of operational domains to include all but Class A airspace is an important financial consideration.

Reduction of costs is also essential to help build the business case for a UAS C2 network. This is the reason the Study Team is advocating the sharing use of first responder infrastructures through government agreements. This means using high-density first responder terrestrial cellular towers networks with power redundant systems and ground communication infrastructure ostensibly without costs, with marginal costs, or with shared costs.

The future development of FirstNet will upgrade much of today's LMR first responder network and add assets to expand to a nationwide mission critical 4G LTE (Long Term Evolution) broadband environment with sophisticated capabilities to manage network demand and provide the highest level of security. This offers the opportunity to continue to expand and upgrade an independent UAS C2 network sharing selected FirstNet infrastructure. Again possibly without costs or with marginal costs or shared costs as part of a government-to-government agreement.

As an adjunct benefit FirstNet has been conceptualized from the beginning to be able to use priority and preemption to separate mission critical communications from normal lower priority communications. This enables FirstNet to sell commercial services that can reside on the FirstNet network without interfering with high priority mission critical communications. This would be an ideal method of bundling UAS C2 and payload to maximize revenues.

Public support is absolutely essential for creating a viable and sustainable UAS C2 system; however, the support does not necessarily have to be financial. Other very useful and critical forms of support needed from Government, which do not involve funding, are as follows:

- Legal Framework – providing a basis by which the UAS C2 corporation is empowered to execute its business

operations without fear of being regulated or legislated out of business;

- In-kind Resources –assets owned by Government that can be brought to bear to the UAS C2 problem. The primary instance of this is the telecommunications spectrum that will be used; there could be others;
- Coordination of Agency Requirements – Several Federal agencies have interest in how the UAS C2 entity is established, among them the FAA, FCC, and NTIA. Coordinating and aligning their respective requirements would simplify the process of the UAS C2 entity meeting its compliance responsibilities with these agencies.

The best operating model for the UAS C2 business appears to be the “Single Regional Network Provider.” As the UAS market grows over time, there may be an opportunity to open the market to competition from multiple providers; however, this is not expected to occur until around 2025 at the earliest.

A corporation set up for the purpose of managing command and control of UAS BLOS operations can be not only technically viable, but also profitable. Our estimate based on a startup P&L analysis is that prices paid by users for the service are likely to be affordable and sustainable, beginning at around \$37 per flight in 2018 and falling to about \$12 per flight over the next 15-20 years. The significance of these price levels is that the costs to users of UAS traffic management should not be an impediment to the growth of the UAS industry at any stage of its development.

4. CONCLUSIONS / NEXT STEPS

The realistic study scenarios as outlined above definitely proved valuable and should be adopted as a framework for future study. It exposed many interrelated issues concerning command and control of UAS such as: frequency management, network management, operational flight planning, integration with other air traffic, etc. The realistic scenarios also revealed that there is no one solution that fits. Point-to-Point Beyond Line-of-Sight (PBLOS) offers lower implementation and operating costs while Networked Beyond Line-of-Sight (NBLOS) promises higher capacity and a richer potential feature set. Policy decisions based on PTP and Network C2 Systems as separate and distinct classes should be discouraged because PTP, Hybrid, and Network C2 systems can be viewed as three stages in an operational continuum of the same basic C2 architecture and infrastructure. Maintaining the PTP (or “Standalone”) vs. Network distinction has been unnecessarily polarizing.

Establishing a flexible and interoperable C2 system will become much more difficult without technical standards. Lack of UAS C2 technical interoperability standards (at the appropriate protocol layers) presents a serious impediment to the widespread and harmonious implementation of UAS C2 systems and associated spectrum allocations/assignment

processes. These should be given a higher priority in future standards development activities.

Collaboration is paramount for the future of BLOS C2 of UAS and for UAS operations writ large. Attendance numbers at recent UAS events and the many stories in the media show that interest is high. There are many stakeholders in the UAS community, and both industry and policy makers should collaborate to help balance between the flexibility needed for innovation and standardization needed for safe integration of UAS into the national airspace system.

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BIOGRAPHY



Ms. Denise S. Ponchak is the Deputy Branch Chief of the Communications Architectures, Networks and Systems Branch at the National Aeronautics and Space Administration's (NASA) Glenn Research Center at Lewis Field in Cleveland, Ohio. The Branch is responsible for designing advanced networking concepts, architectures, technologies and system integration for aeronautics and space applications. Prior to becoming a supervisor, Ms. Ponchak was an Aeronautical Communications Project Manager focusing on increasing the National Airspace System's telecommunications capability, and a communications research engineer supporting future satellite-based communications. She holds a Bachelor's of Electrical Engineering and a Master's of Science in Electrical Engineering from Cleveland State University in 1983 and 1988 respectively. Denise is a Foodie who likes to hike, ski and travel.



Ms. Elisabeth Auld is the Deputy Director of the NextGen Institute in Washington DC. The NextGen Institute represents a partnership between the government and private sector to work together on the definition, goals, development, and implementation of NextGen and serves as the mechanism for gathering and applying the best expertise in support of NextGen, encouraging the development of transformational ideas, and sustaining a long-term undertaking by promoting joint solutions and coordinated investments. Prior to joining the NextGen Institute, she was an officer in the Air Force where she worked in air traffic control, airfield management, human resources, requirements and budget development and had executive experience as a squadron commander forward deployed to northern Iraq. Her final assignment in the Air Force was the Director of Staff for the Director, Air Force Public Affairs. In her spare time, she likes to design jewelry, blog and pursue photography.



Mr. Gary Church is President of Aviation Management Associates, Inc. of Alexandria, Virginia. Prior to becoming the principal of AMA in 1984, he was Manager of Air Traffic Control for the Air Transport Association in Washington, DC where he worked closely with the FAA to develop and implement plans for the air traffic controller's strike of 1981. Prior to joining ATA, Mr. Church was an air traffic control specialist at the Indianapolis Air Route Traffic Control Center from 1971 until 1980 where he had a variety of controller and staff responsibilities. Mr. Church has had 45 years as an active instrument rated pilot and currently flies a Cirrus SR22. In addition to his love of flight, he jams guitar with friends, scuba dives around the world with his wife, and pursues his passion of racing Porsches throughout the United States.

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